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WASHINGTON, D.C. 20007

DEPARTMENT OF THE NAVY

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EVALUATION OF TWO METHODS FOR PREDICTING
TOWLINE TENSIONS AND CONFIGURATIONS
OF A TOWED BODY SYSTEM USING BARE CABLE

by
Thomas Gibbons and C. O. Walton

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EVALUATION OF TWO METHODS FOR PREDICTING TOWLINE TENSIONS AND CONFIGURATIONS OF A TOWED BODY SYSTEM USING BARE CABLE

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Report 2313
S-F006 03 02
Task 7462

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NOTATION

C_R Drag coefficient, $\dfrac{R}{\frac{1}{2}\rho\, d\, V^2}$

d Diameter of cable

F Drag per unit length of cable when cable is parallel to the stream

f Ratio F/R

R Drag per unit length of cable when cable is perpendicular to the stream

s Scope (length) of cable

T Cable tension at the ship

T_o Cable tension at the towed body

V Speed

W Weight in water per unit length of cable

y Depth

ρ Mass density of the fluid

ϕ Cable angle

ABSTRACT

Two alternative methods for predicting steady-state configurations and towline tensions are evaluated by comparing predicted data with experimental data. Between the two methods, Method 1 is shown to provide better overall predictions of cable tension, cable angle at towing ship, and body depth for the bare-cable case. The best agreement between the experimental data and the data predicted by Method 1 is obtained with a cable drag coefficient of 1.5 and a tangential force factor of 0.02.

INTRODUCTION

The David Taylor Model Basin is engaged in a broad research program directed toward the development of improved experimental and analytical techniques for predicting the steady-state and dynamic characteristics of cable-towed systems. Pursuant thereto, a project was initiated to determine which of the various existing methods would provide the most accurate predictions of the steady-state configurations and associated towline tensions for cable-towed bodies. The project is being carried out in two phases; one involving the use of bare cables and the other involving the use of faired cables. This report deals with the first phase, and is confined to an evaluation of the two methods most commonly used by the Model Basin. The investigation was carried out in conjunction with Bureau of Ships Subproject S-F006 03 02, Task 7462.

The need for improved towing capabilities and the requirements for cable-towed-sonar, detection, surveillance, and decoy systems have been greatly emphasized by the advent of high-speed, nuclear-powered, submarines and surface ships. Also, the increased emphasis in oceanography and deep-water search activities indicates a greater use of cable-towed devices. A more exact knowledge of the configuration and forces produced by most of these systems will be required since they must be accurately located relative to the towing platform for detection, tracking, and fire control purposes. Furthermore, housing and power restrictions of many towed systems preclude the installation of instrumentation to monitor the towing configuration and forces during operation.

To carry out the objectives of the subject program, the Model Basin equipped an existing body with special purpose instrumentation and towed it at sea by bare cable to obtain steady-state configuration data. The experimental data were then compared with corresponding values obtained by means of each of the two prediction methods. Based on these comparisons, a set of "loading functions" was selected that should result in reasonably accurate predictions of steady-state configurations and tensions for body-dominated towed systems.

This report describes the towed system, associated equipment, and the experimental program used to provide the fundamental data for the investigation; discusses the computer program used for the analysis;

compares the experimental and predicted results; presents conclusions concerning the use of the two methods for predicting the configuration and forces for a bare-cable towed system; and makes recommendations for the use of a standard prediction method and associated loading force coefficients for the case of bare towcables.

GENERAL CONSIDERATIONS

The steady-state equations of a cable-body system expressed in terms of the hydrodynamic and hydrostatic forces acting on an element of cable are given in Reference 1.* A diagram showing how these forces are resolved is reproduced as Figure 1. Once the hydrodynamic characteristics of the towed body and the towing cable are known, the cable configuration and tension can be determined from the equations. Generally, the hydrodynamic characteristics of the towed body are known or can be readily obtained. However, there are little data concerning the exact magnitude of the hydrodynamic forces acting on the element of cable. Consequently, the usual practice is to assume that these forces are some predetermined function of the angle that the cable makes to the stream. Several attempts have been made by investigators in the past to measure or resolve these cable forces[2,3,4,5,6]. However, these attempts have been hampered by inadequate instrumentation to measure the minute tangential forces involved, as well as a variety of experimental difficulties such as mounting techniques to avoid gap effects, end effects, etc., and thus obtain reliable two-dimensional data. Furthermore, such factors as cable strands, roughness, and cable vibration may affect the forces on a cable. The cable strands and roughness may cause turbulent flow over the element of cable which could either increase or decrease the hydrodynamic forces depending on the Reynolds number. If the cable is vibrating, the effective frontal area is increased and hence, the forces are increased. Severe vibration usually occurs in bare-cable towing operations.
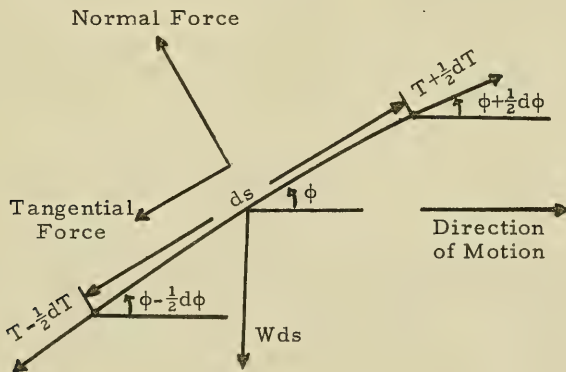
Figure 1 - Forces Acting on an Element of Cable

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* References are listed on page 39.

In spite of the aforementioned uncertainties, the basic differential equations have been generally accepted and used, but various agencies have developed different expressions for the hydrodynamic loading forces on an element of cable. The two methods most commonly used by the Model Basin to predict the steady-state characteristics of cable-towed body systems are described in References 1 and 7, and are designated herein as Methods 1 and 2 respectively. The two methods are essentially the same but differ in the loading functions which are used. Both methods resolve the hydrodynamic force into normal and tangential components, as shown in Figure 1. The expressions used for the hydrodynamic force components for each method are compared in Table 1. It may be noted that the tangential force in Method 1 is independent of the cable angle, whereas in Method 2 it is a function of cable angle.

TABLE 1

Assumed Expressions for Hydrodynamic Force Components Used
in Methods 1 and 2

Method	Normal Force	Tangential Force
1	$R \sin^2 \phi$	$R f$
2	$R \sin^2 \phi$	$R \left[0.083 \cos \phi - 0.035 \cos^2 \phi \right]$

The Model Basin has a computer program for calculating the equilibrium configuration of a flexible cable in a uniform stream[8]. The program is based on the differential equations of References 1 and 7 which assume that the velocity at the element is constant and is not affected by curvature of the cable. It further assumes that the cable is inelastic and offers no resistance to bending. When the hydrodynamic forces acting on the cable-body system are known, the predicted configuration may be computed to an accuracy of ±0.001 percent for each integration step. The exact configuration, then, is primarily dependent upon the accuracy of the input data used in the program. The computer program is set up to allow a choice of the two methods to predict the cable configuration and towline forces.

DESCRIPTION OF EXPERIMENTAL EQUIPMENT

The towcable used in this investigation is shown by Figure 2 and a detailed description is given in Reference 9. It is a 0.350 (±0.005)-inch-diameter, double-armored, electrical cable which consists of two layers of steel armor strands surrounding an eight-conductor (four coax) electrical core. The under layer of armor consists of eighteen strands with a 2.0 (±0.2)-inch right-hand lay. The outer layer consists of twenty-four strands with a 3.0 (±0.2)-inch left-hand lay. Each strand is 0.0375-inch-diameter, Type 304, corrosion-resistant steel. The cable weighs 0.169 pound per foot in salt water (70 degrees F) and has a breaking strength of approximately 10,000 pounds.

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Figure 2a - Towcable

Figure 2b - Towed Body

Figure 2—Photograph of the Towcable and Towed Body

The towed body used in the experimental phase of the investigation is also shown in Figure 2. The towed body is a body of revolution constructed of fiberglass and is equipped with a depressing wing located on its horizontal centerline and has a set of control surfaces located on its aft section to provide the necessary stabilizing forces. Table 2 gives all the pertinent information of the body and cable.

An instrument package, housed within the towed body, contains the transducers and electronics to measure the hydrodynamic parameters. A pressure transducer was used to obtain the depth. Roll, pitch, and cable angle at the body were obtained with pendulum potentiometers. The tension at the body was obtained with a strain-gage element in the towstaff. All the data from the body was transmitted through the towcable to shipboard recorders. At the shipboard end, the cable angle was measured with a potentiometer transducer and the cable tension was obtained from a strain-gaged load cell. A modified version[10] of the DTMB Mark 1 Knotmeter[11] was used during the tests to obtain the towing speed of the ship relative to the water. A complete description of the instrument package and components is given in Reference 10. Although the tension produced by the body at high speeds exceeded the design measurement range of the tension gage by about 30 percent, it is felt that this should not significantly affect the accuracy of the measurements.

TABLE 2

Physical Characteristics of Cable and Body

Cable	
Diameter, inches	0.350
Weight in sea water, pounds per foot	0.169
Number of electrical conductors	8
Body	
Overall length, inches	61.0
Maximum diameter, inches	14.5
Fineness ratio	4.2
Weight in sea water, pounds	100.0
Wing	
Span, inches	32.5
Planform area, square inches	362.0
Aspect ratio	2.9
Incidence angle (leading edge down), degrees	6.0
Tail Fins (Horizontal and Vertical)	
Span, inches	20.6
Planform area, square inches	202.0
Aspect ratio	2.1
Incidence angle, degrees	0
Shroud Ring	
Diameter, inches	20.6
Chord, inches	4.9
Total area, square inches	320.0

TEST ARRANGEMENT AND PROCEDURES

The experimental data were obtained during sea trials which were conducted in deep water off the Bahama Islands. Figure 3 is a schematic diagram of the towing arrangement. The towed body was launched from the ship and cable was reeled out to a predetermined nominal scope. The nominal scope is defined as the amount of cable in the water at essentially zero speed. For test purposes, nominal scopes of 100, 200, and 280 feet were used.

All tests were conducted in Sea States of 0 to 1/2 to obtain as near steady-state conditions as possible. The roll and pitch of the body were monitored during the tests to insure the proper orientation of the body. In general, the roll angle was about zero (within ±1 degree) and the pitch angle was about 6 degrees nose down.

The body was towed at speeds from 2.5 to 10.5 knots with the cable scope held fixed at each of the three nominal values. The following parameters were measured and recorded:

1. body depth
2. body pitch angle
3. body roll angle
4. cable angle at the body
5. cable tension at the body
6. cable angle at the ship
7. cable tension at the ship
8. speed of the ship relative to the water

PRESENTATION OF EXPERIMENTAL RESULTS

The experimental values of tension, depth, and angle for the three nominal cable scopes obtained from all of the tests are tabulated and presented in Appendix A. To illustrate the quality of the measurements, the data for a representative case (280-foot nominal cable scope) are presented in graphical form in Figures 4, 5, and 6. Figure 4 presents the measured cable tension at the ship as a function of speed. Figure 5 is the measured depth of the towed body as a function of speed. Figure 6 is the cable angle at the ship as a function of speed. It may be noted that at speeds above 4 knots, there is very little scatter in the data on depth and cable angle. As may be expected, the tension data show more scatter since the cable was vibrating and the ship was pitching and heaving slightly. However, the faired curve should be closely representative of the mean tension values corresponding to any given steady-state condition.

WATER SURFACE

TOWING SHIP

TOWCABLE

TOWED BODY
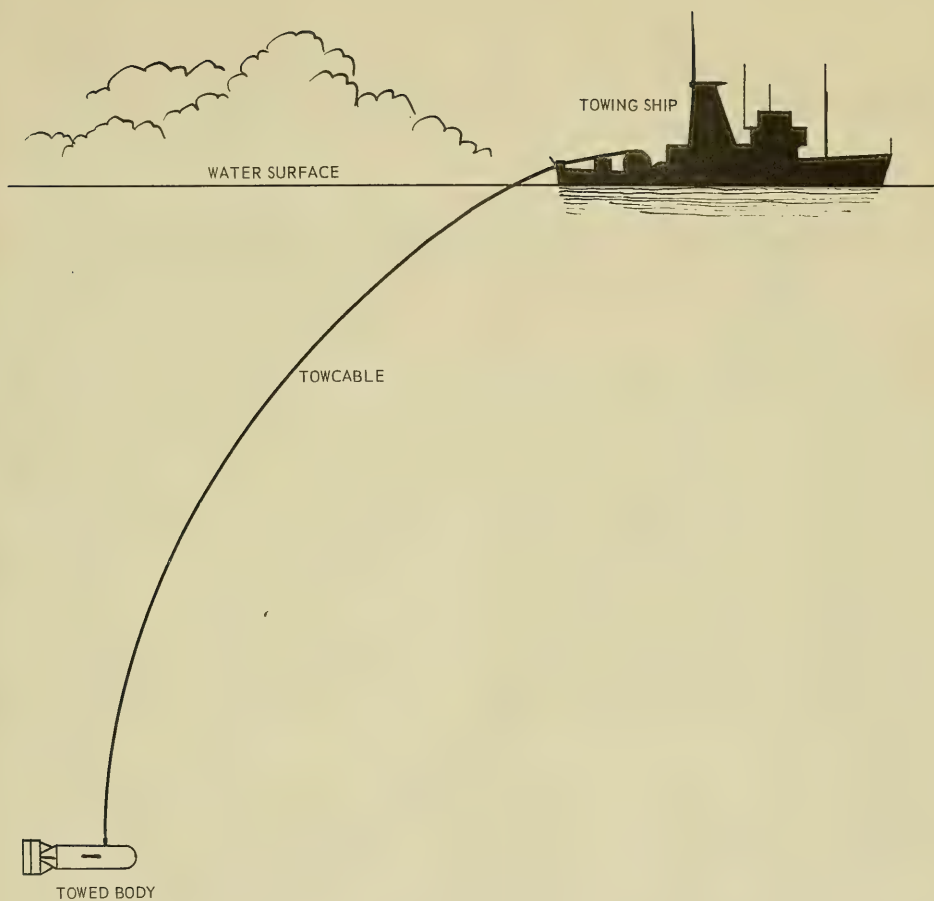
Figure 3—Schematic Diagram of the Towing Arrangement
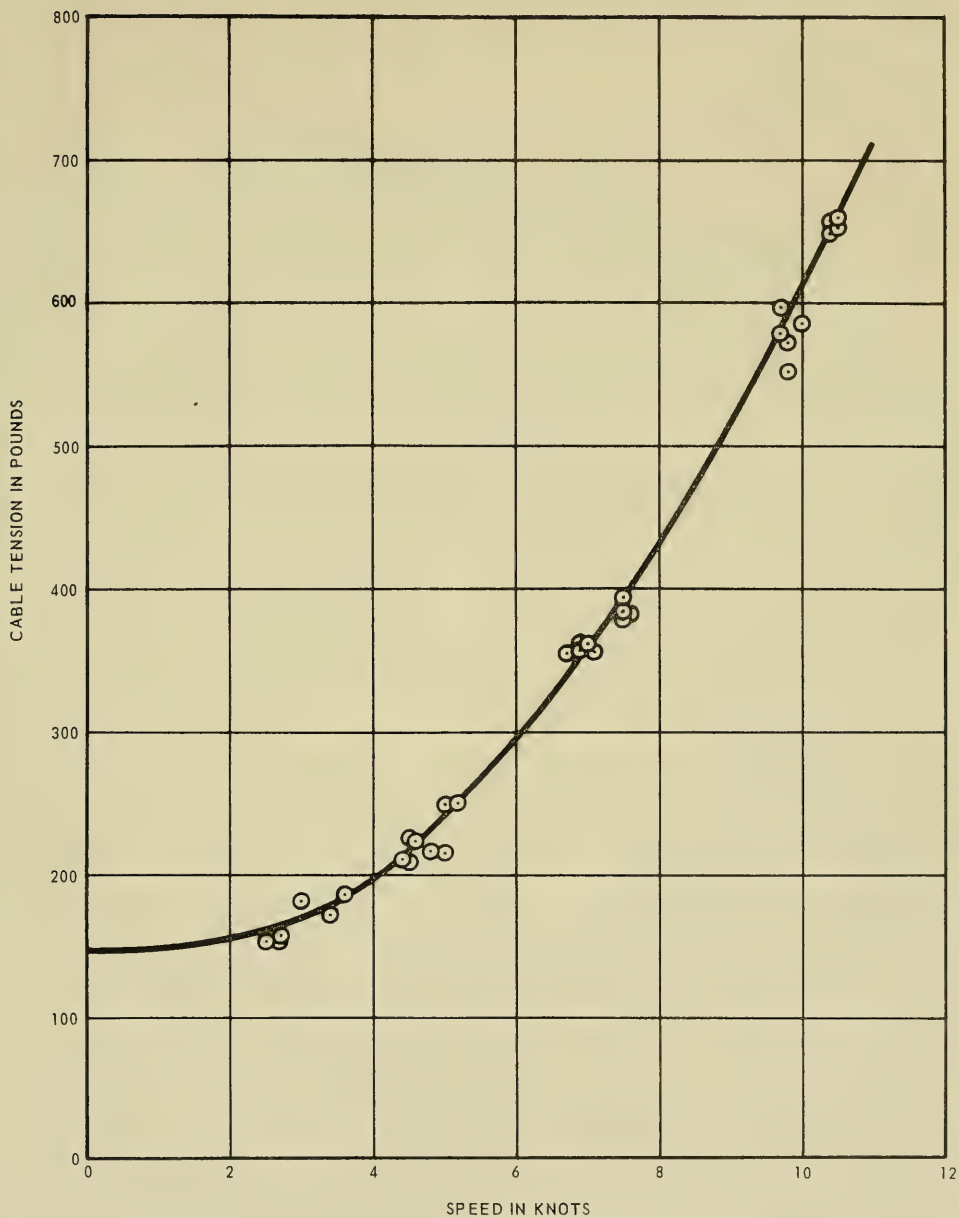
Figure 4—Measured Cable Tension at the Ship as a Function
of Speed for the 280-Foot Nominal Cable Scope
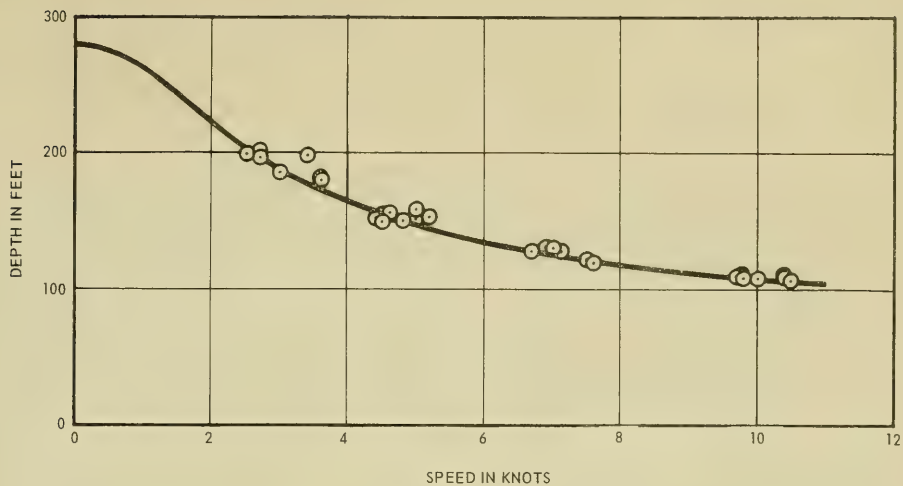
Figure 5—Measured Depth as a Function of Speed for the
280-Foot Nominal Cable Scope
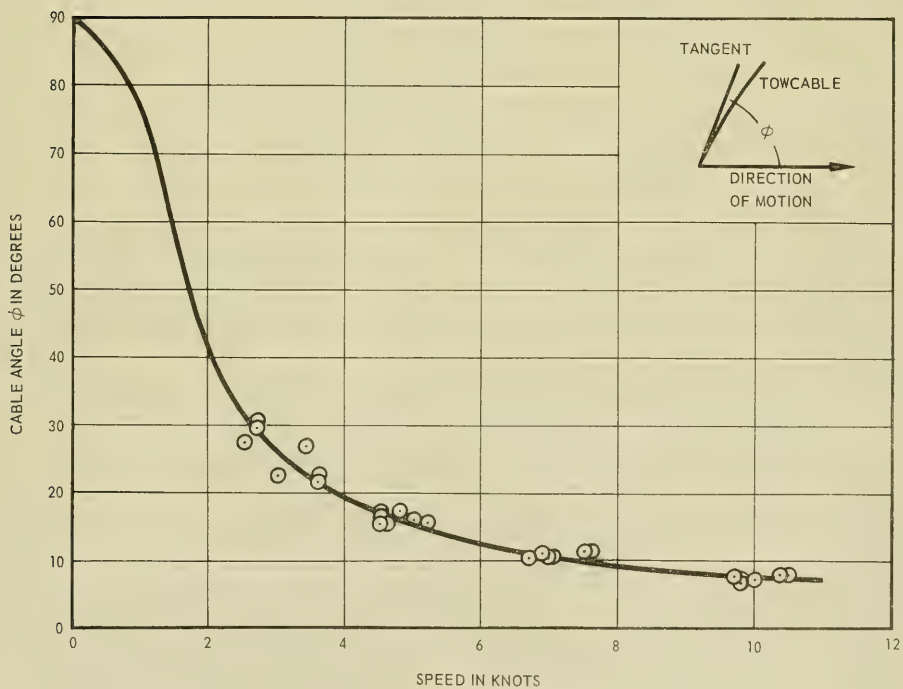
Figure 6—Measured Cable Angle at the Towing Ship as a Function
of Speed for the 280-Foot Nominal Cable Scope

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PARAMETRIC STUDIES WITH TWO PREDICTION METHODS

Prior to making direct comparisons between measured and predicted results, computations were made to determine the effect of arbitrary parametric variations on the cable configurations and tensions computed by each of the two methods using the hydrodynamic characteristics of the body, given by the faired curves in Figure 7. The cases considered were for scopes of 100, 200, and 280 feet. For Method 1, cable drag coefficients C_R of 0.8, 1.5, and 1.8 in combination with f values of 0.01, 0.02, and 0.03 were used for the computations. For Method 2, cable drag coefficients of 0.8, 1.5, and 1.8 were used. The results of these computations for Methods 1 and 2 are presented in tabular form in Appendixes B and C, respectively, and selected representative cases (280-foot scope) are shown in graphical form in Figures 8 through 13.

The effects of variations of C_R and f values on the depth y, net tension $T-T_o$, and cable angle ϕ are summarized for the two methods by Table 3. The values in the table correspond to the case of a cable scope of 280 feet and a speed of 11 knots. The net tension $T-T_o$ is the difference between the tension at the ship T and the tension at the towed body T_o. Consequently, it is due only to the hydrodynamic and hydrostatic forces acting on the cable.

TABLE 3

Effect of Parametric Variations on
Predictions with Methods 1 and 2

(Values are for a speed of 11 knots, a scope
of 280 feet, and a tension at the body of
637.0 pounds)

Table 3a - Effect of Variation of C_R

C_R	Method 1 (f = 0.02)			Method 2		
	y	$T-T_o$	ϕ	y	$T-T_o$	ϕ
0.8	125.5	70.6	17.4	153.4	120.8	17.8
1.5	109.3	102.5	10.4	110.8	207.1	10.9
1.8	98.3	117.5	9.0	99.9	245.5	9.5

Table 3b - Effect of Variation of f

f	Method 1(C_R = 1.5)		
	y	$T-T_o$	ϕ
0.01	108.5	60.4	10.2
0.02	109.3	102.5	10.4
0.03	110.1	144.7	10.6
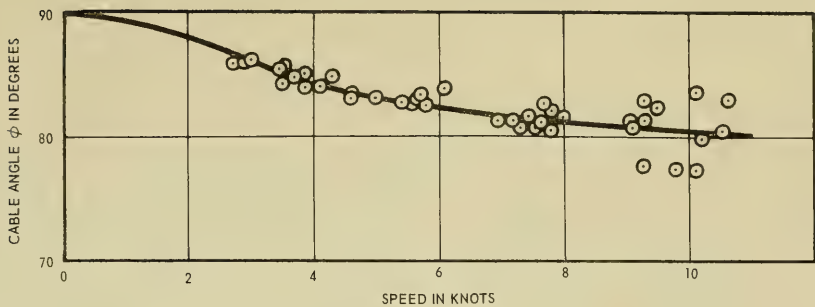
Figure 7a - Cable Angle
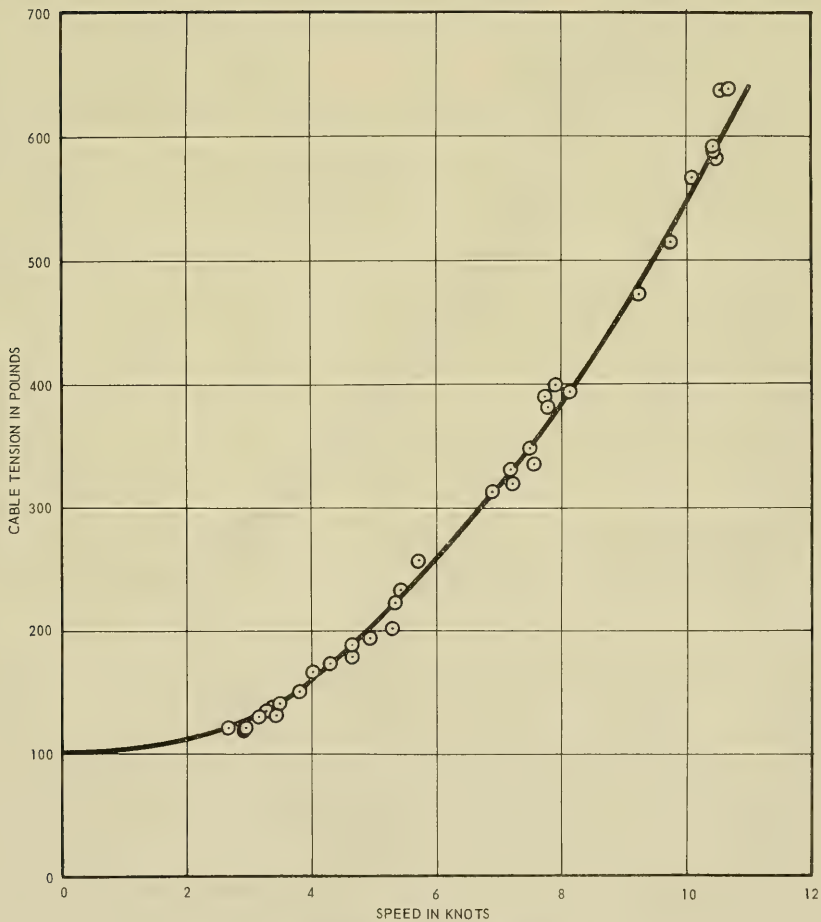
Figure 7b - Cable Tension

Figure 7—Measured Cable Angle and Tension at the Body as
a Function of Speed
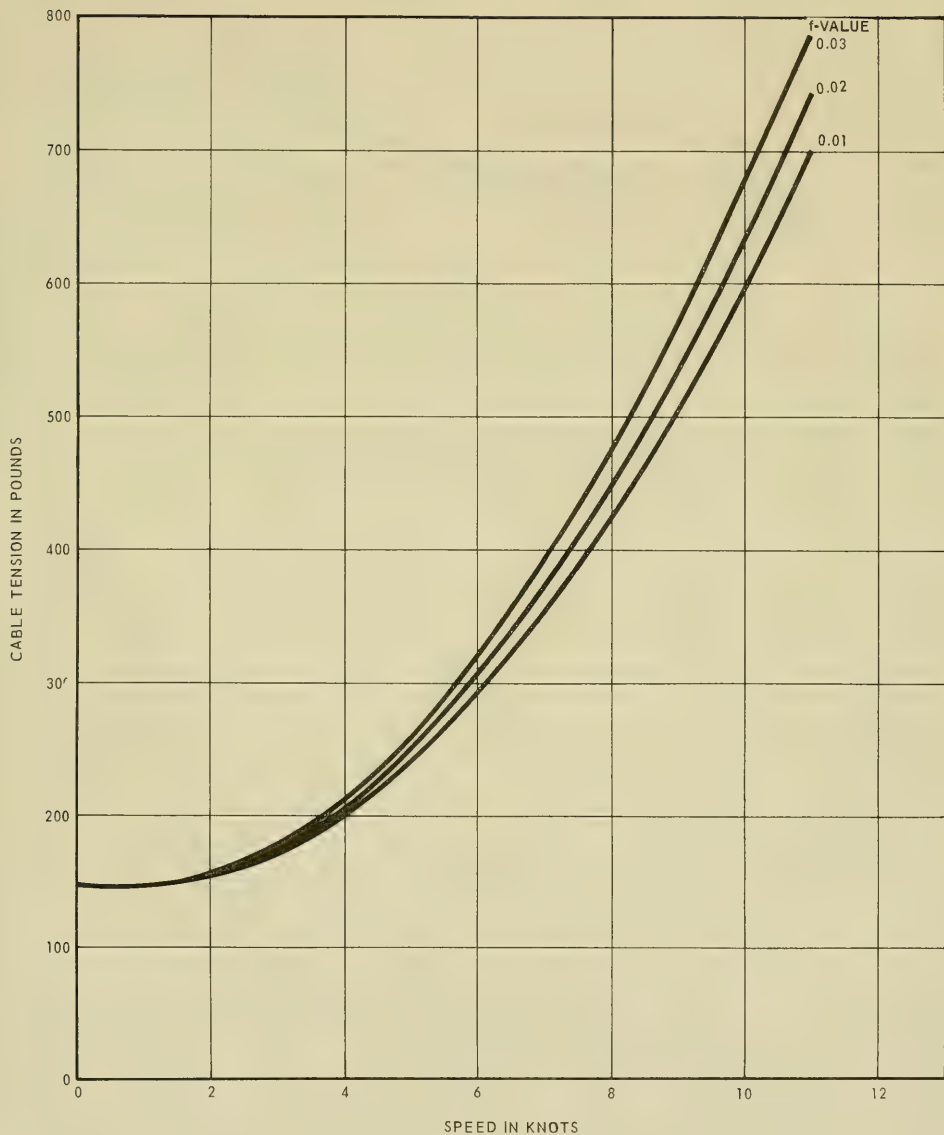
Figure 8—Method 1 - Effect of Variation of f-Value on Tension at Ship
for a Drag Coefficient of 1.5 and a Cable Scope of 280 Feet

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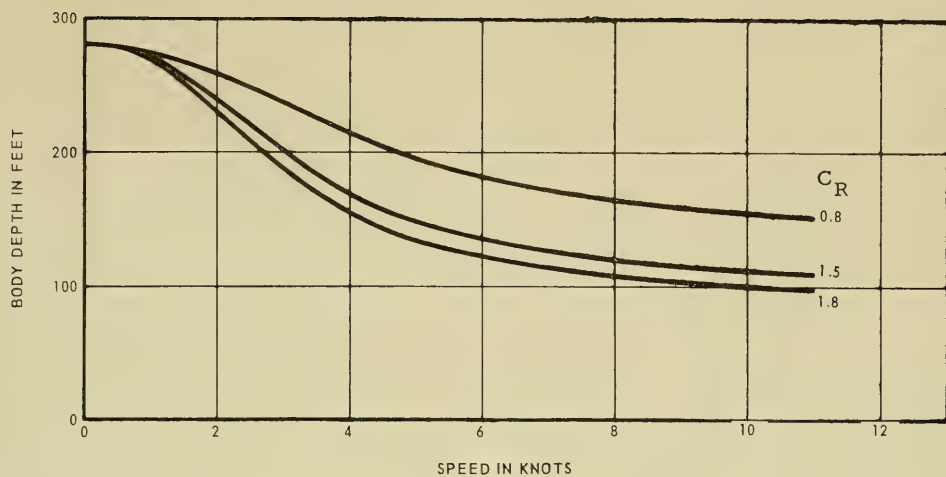
Figure 9—Method 1 - Effect of Variation of Drag Coefficient on Body
Depth for an f-Value of 0.02 and a Cable Scope of 280 Feet
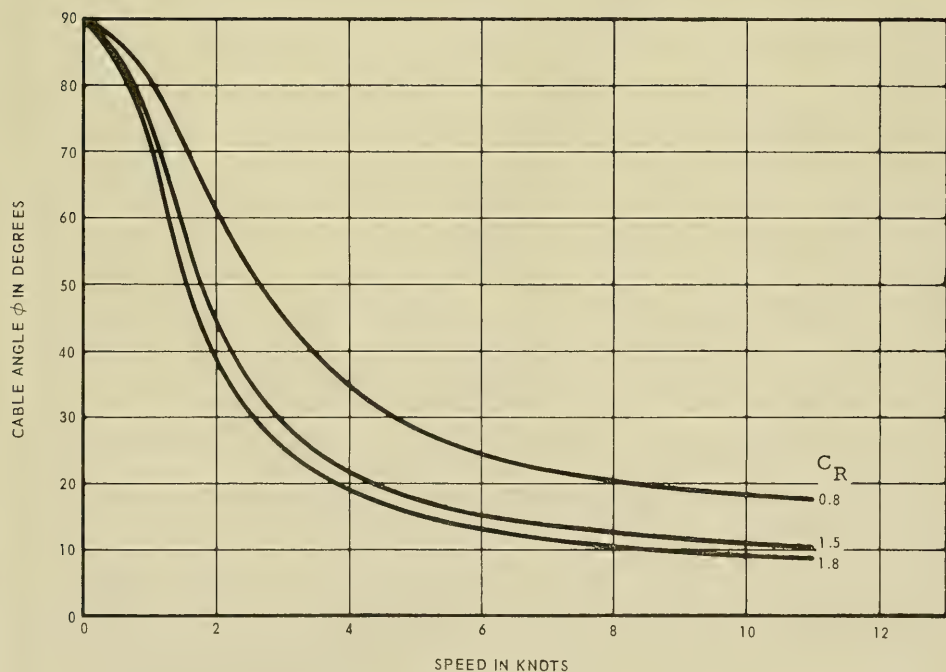
Figure 10—Method 1 - Effect of Variation of Drag Coefficient on Cable
Angle at Ship for an f-Value of 0.02 and a Cable Scope of 280 Feet

13
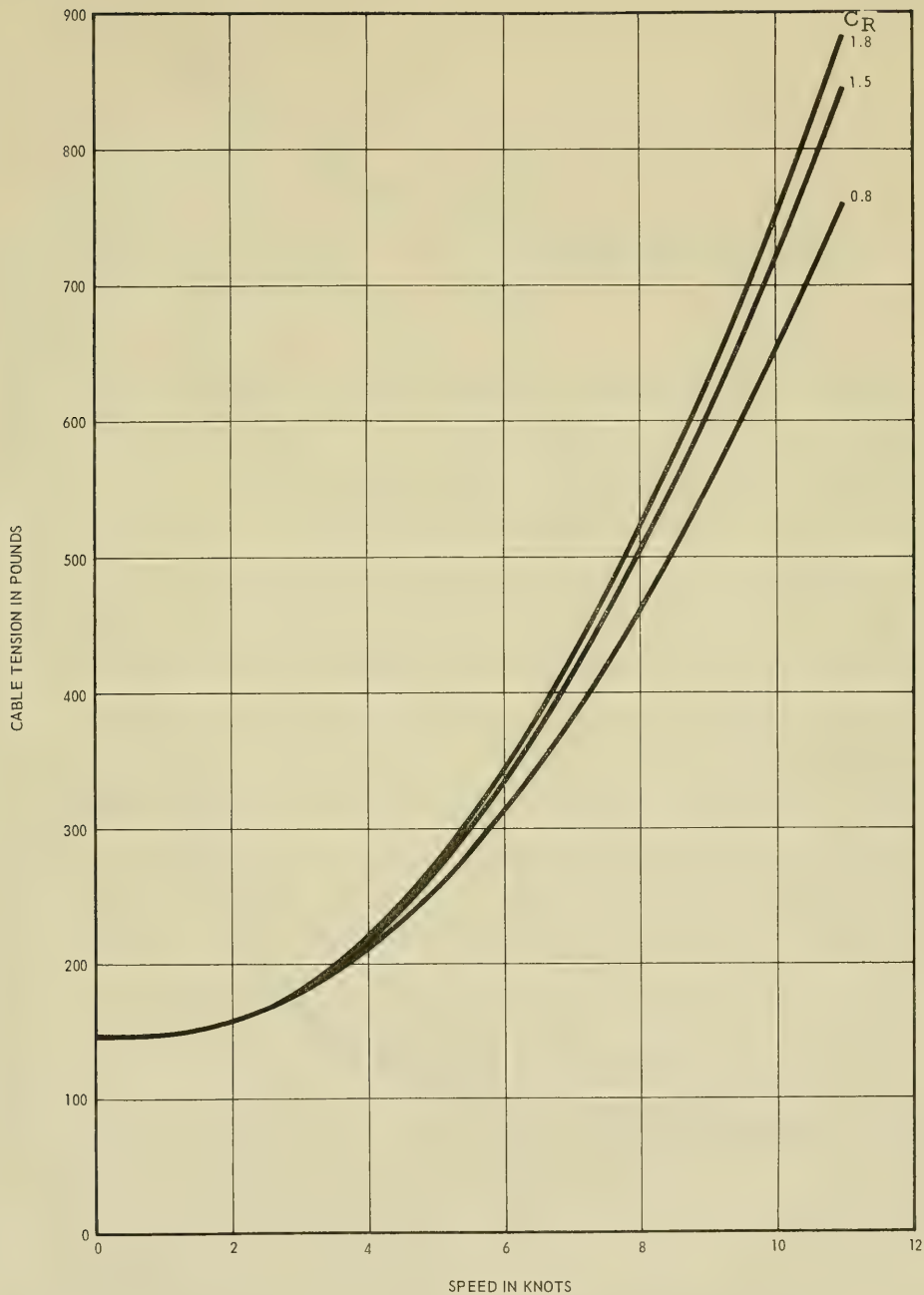
Figure 11—Method 2 - Effect of Variation of Drag Coefficient on
Tension at Ship for Cable Scope of 280 Feet

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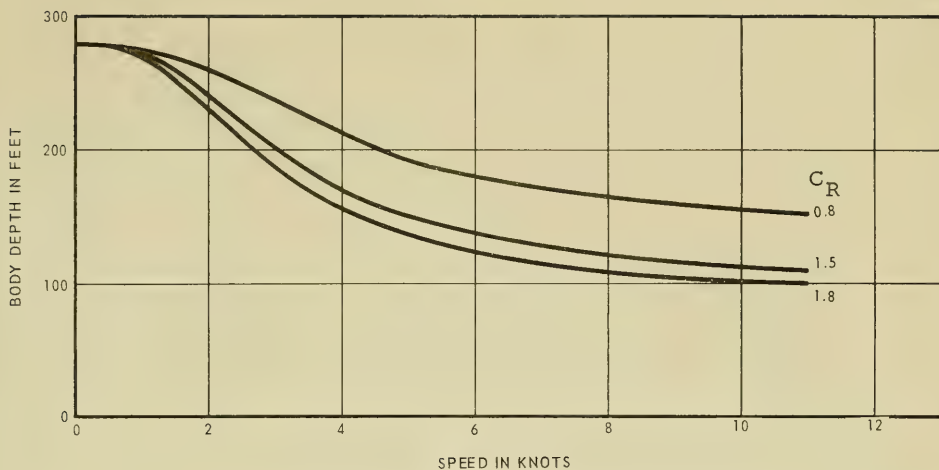
Figure 12—Method 2 - Effect of Variation of Drag Coefficient on
Body Depth for Cable Scope of 280 Feet
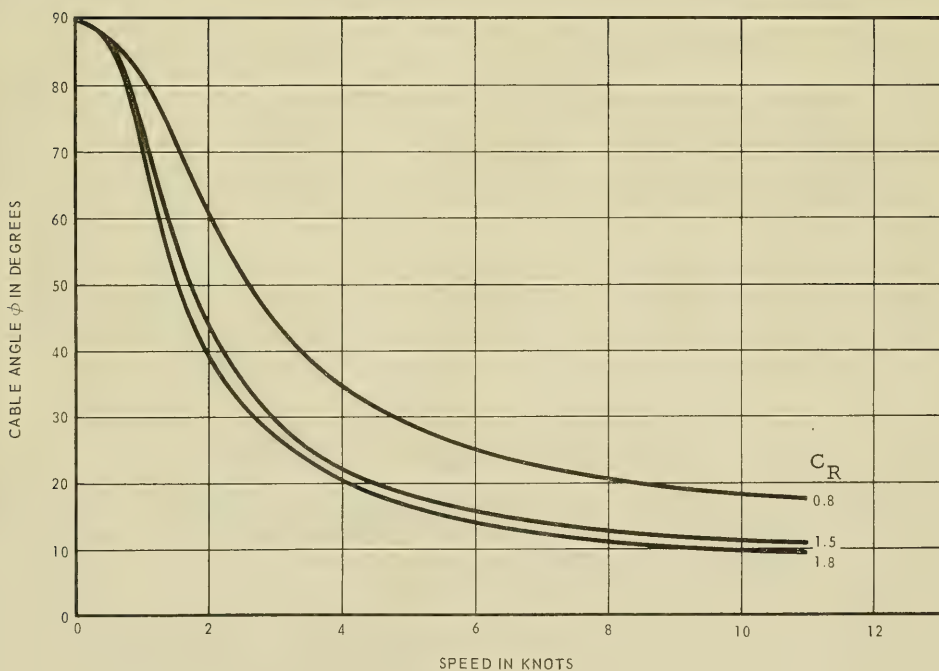
Figure 13—Method 2 - Effect of Variation of Drag Coefficient on
Cable Angle at Ship for Cable Scope of 280 Feet

For Method 1, within the range shown in Table 3, the variation in C_R has a significant influence on all three quantities. However, the variation in f has little effect on depth and cable angle but has considerable influence on the net tension. Thus, if a drag coefficient is selected to give good agreement between predicted and measured values of depth and cable angle, a value of f can be selected which will give good agreement on net tension as well.

For Method 2, within the range shown in Table 3, the variation in C_R also has a significant influence on all three quantities. In this case, the only value that can be changed in any given computation is the cable drag coefficient. Consequently, if good agreement cannot be obtained with one value of drag coefficient for all three quantities, then changes in the drag coefficient to improve the agreement with one of the quantities will result in poorer agreement with the other two quantities.

COMPARISON OF MEASURED AND PREDICTED RESULTS

Since the towpoint at the ship was above the water surface, the length of the cable in the water changed with ship speed. Nevertheless, for simplicity, the nominal scopes were used in making comparisons between the measured and computed values. This simplification is considered justified in view of the scatter in the experimental data.

Based on the computer study described by the preceding section, selections were made of the numerical values of the pertinent parameters to be used in the predictions involving each of the two methods. The selected values were those which gave the best overall fit to the measured data on cable tension, cable angle, and body depth. On this basis, a $C_R = 1.5$ in combination with an f = 0.02 was found to be best for Method 1 and a $C_R = 1.5$ was found to best for Method 2. The predictions based on the selected values for each method (Tables 10e and 13b) are compared with the measured data (Table 7) in Figures 14, 15, and 16 for the nominal cable scope of 280 feet. In addition, the differences between the predicted and measured data (faired curves) for the three nominal scopes are summarized in Table 4 for a speed of 10 knots.

TABLE 4

Difference Between Predicted and
Measured Data at a Speed of 10 Knots

Parameter	100-foot scope		200-foot scope		280-foot scope	
	Method 1	Method 2	Method 1	Method 2	Method 1	Method 2
Tension, lb	-5	25	20	80	25	110
Depth, ft	2	2	2	2	3	4
Angle, deg	-1.5	- 1.5	3.0	3.0	3.5	4.0
NOTE: Positive values signify that the predicted value is larger than the measured value. The predicted values are based on a C_R of 1.5 and an f of 0.02.						

16
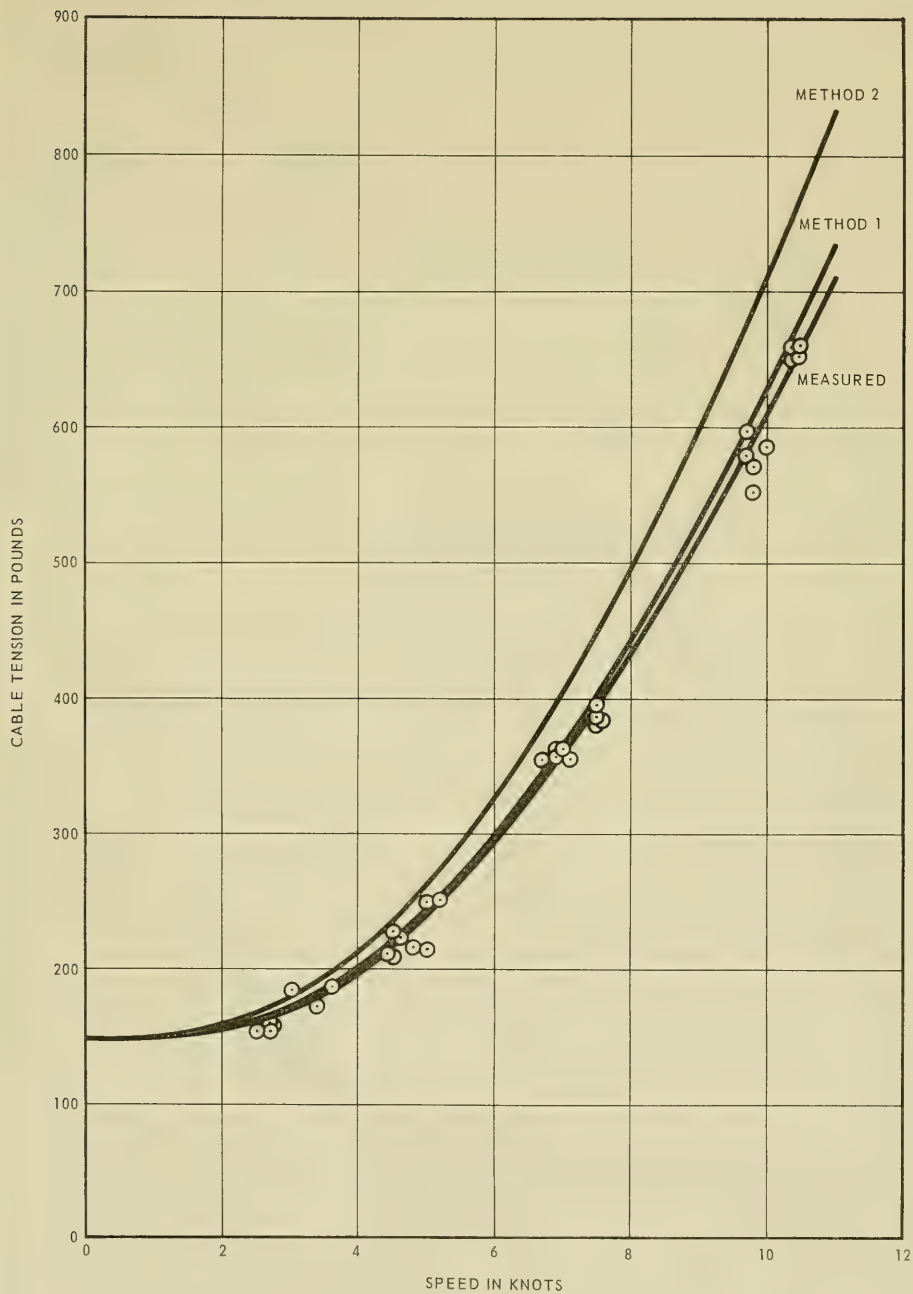
Figure 14—Comparison of Measured and Predicted Cable Tension at the Towing Ship as a Function of Speed for a Nominal Cable Scope of 280 Feet

17
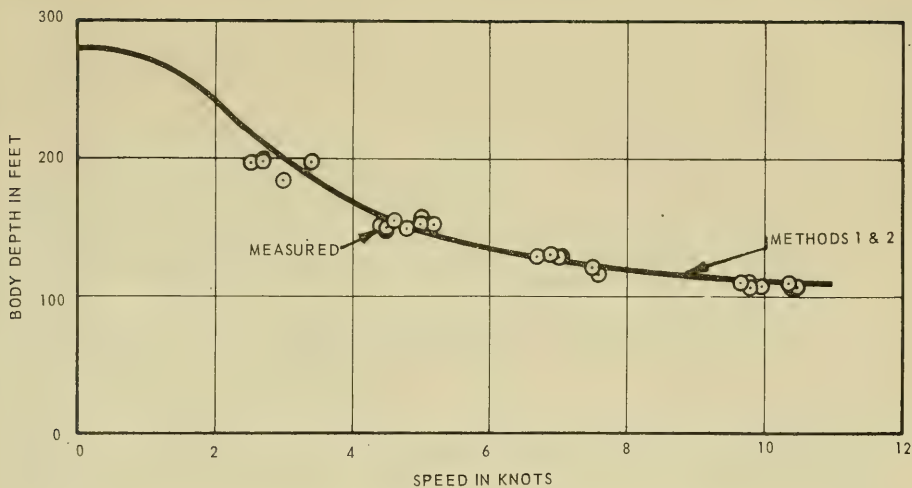
Figure 15—Comparison of Measured and Predicted Body Depth as a Function of
Speed for a Nominal Cable Scope of 280 Feet
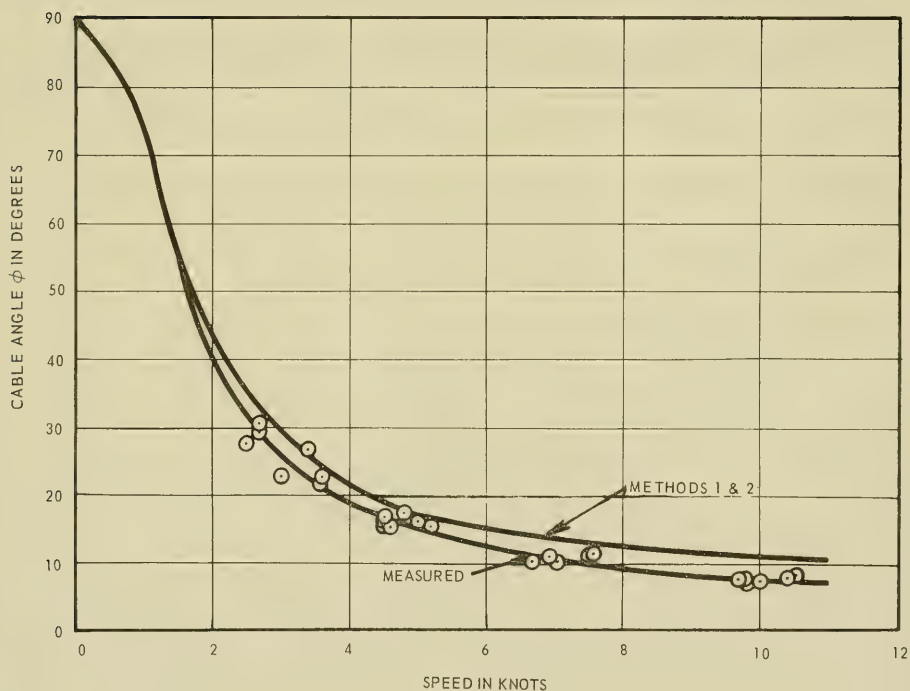
Figure 16—Comparison of Measured and Predicted Cable Angle at the Towing Ship
as a Function of Speed for a Nominal Cable Scope of 280 Feet

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Figure 14 and Table 4 show that the total tensions predicted using Method 1 are in close agreement with the measured values. For the 280-foot scope, the agreement is within about 4 percent at 10 knots. On the other hand, the total tensions predicted using Method 2 are substantially higher than the measured values. For the 280-foot scope, the predicted value is about 17 percent higher than the measured value at 10 knots. It should be noted that these comparisons are based on the total tensions rather than the net tensions discussed earlier. As such, they include the tension due to the body and the weight of the towcable as well as the contribution of the hydrodynamic force acting on the cable.

Figure 15 and Table 4 show that both methods provide reasonably close predictions of body depth over the entire range of speeds and scopes investigated.

Figure 16 and Table 4 show that the predictions of the cable angle obtained by both methods are in close agreement; however, the predicted angles are slightly larger than the measured values except for the 100-foot scope.

Although the total tension predicted by Method 1 is in close agreement with the measured values, it should be understood that even for the 280-foot scope, the total tension at the ship is due predominantly to the forces acting on the body rather than on the cable (body-dominated system). This is typical of a wide variety of cable-towed body systems. However, there are some systems of interest that are essentially cable dominated. It is believed that an additional set of specialized experiments should be conducted to provide data to validate a prediction method for this type of system.

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CONCLUSIONS AND RECOMMENDATIONS

Based on an evaluation of two alternative methods for predicting steady-state towing configurations and towline tensions of a cable-body system towed by bare cable, and comparisons made between predictions and measurements obtained from towing experiments conducted at sea, the following conclusions are drawn:

1. Within the range investigated, Method 1 is the best of the two methods from the standpoint of providing better predictions of both the steady-state tensions and configurations for a body-dominated cable-towed-body system utilizing bare cable.

2. Using a cable drag coefficient $C_R = 1.5$ and a tangential force factor $f = 0.02$, Method 1 can be used with reasonable accuracy to predict the cable tension, the cable angle at the towing ship, and the body depth for the case of a body-dominated system utilizing a bare cable.

3. Using a cable drag coefficient $C_R = 1.5$, Method 2 can be used to predict the body depth and the cable angle at towing ship, but will tend to predict cable tensions that are too high in the case of a body-dominated system utilizing bare cable.

4. Additional experiments are required to determine whether Method 1 can be extended to the case of a cable-dominated system.

In view of the foregoing, it is recommended that Method 1 (using values of $C_R = 1.5$ and $f = 0.02$ until further notice) be adopted as the standard procedure for making predictions of steady-state configurations and tensions for body-dominated towed systems using bare cables.

ACKNOWLEDGMENTS

APPENDIX A

EXPERIMENTAL DATA FOR BARE CABLE
WITH NOMINAL SCOPES OF 100, 200, AND 280 FEET

TABLE 5

Experimental Data for Nominal
Cable Scope of 100 feet

Speed, knots	Depth, feet	Cable Tension at Ship, pounds	Cable Angle at Ship, degrees
2.9	87	122	48.0
2.9	87	122	48.0
2.9	88	121	51.5
3.0	86	123	49.5
3.7	78	164	38.5
3.7	79	162	40.0
3.8	78	161	40.0
3.9	79	163	40.0
3.9	83	183	39.5
4.1	81	196	37.5
4.1	83	184	41.5
4.1	83	191	38.0
5.7	76	277	32.0
5.7	76	279	32.0
5.7	77	276	31.5
6.0	75	272	31.0
7.1	67	355	30.0
7.1	68	331	29.0
7.2	69	346	30.5
7.3	68	356	29.5
7.8	71	400	27.5
7.8	71	401	28.5
7.8	71	409	27.5
7.8	71	409	27.5
10.0	62	635	24.0
10.0	63	612	23.5
10.2	63	585	23.5
10.2	63	611	24.0
10.4	61	614	25.5
10.4	61	625	25.0
10.5	61	627	25.5
10.5	62	619	25.5

TABLE 6

Experimental Data for Nominal
Cable Scope of 200 feet

Speed, knots	Depth, feet	Cable Tension at Ship, pounds	Cable Angle at Ship, degrees
2.9	154	145	33.5
2.9	154	147	34.5
2.9	155	148	34.5
3.1	155	148	35.0
3.3	146	180	28.0
3.4	150	163	27.5
3.4	153	166	29.0
3.7	150	164	28.5
4.5	123	199	21.5
4.6	123	202	22.5
4.6	124	203	22.5
5.3	120	243	20.5
5.3	120	250	20.5
5.3	120	252	20.5
5.6	118	281	19.5
7.1	105	359	13.5
7.2	104	361	13.5
7.3	103	369	13.5
7.4	107	340	13.5
7.5	104	368	16.0
7.6	104	369	15.5
7.6	104	369	16.0
7.7	104	371	15.5
9.0	95	529	11.0
9.3	95	522	11.0
9.4	95	520	11.0
10.5	93	641	12.0
10.5	94	628	11.5
10.5	94	629	11.0
10.5	94	629	11.5

TABLE 7

Experimental Data for Nominal
Cable Scope of 280 feet

Speed, knots	Depth, feet	Cable Tension at Ship, pounds	Cable Angle at Ship, degrees
2.5	197	153	27.5
2.7	197	157	30.5
2.7	198	156	30.5
2.7	199	154	29.5
3.0	185	182	22.5
3.4	197	171	27.0
3.6	179	186	21.5
3.6	181	185	22.5
4.4	151	210	16.0
4.5	148	226	15.5
4.5	150	208	16.5
4.6	155	223	15.0
4.8	150	216	17.0
5.0	154	248	16.0
5.0	157	213	16.0
5.2	153	250	15.5
6.7	128	353	10.5
6.9	131	356	11.0
6.9	131	362	10.5
7.0	129	361	10.5
7.1	128	355	10.5
7.5	121	378	11.5
7.5	121	384	11.5
7.5	121	394	11.0
7.6	118	382	11.5
9.7	109	596	7.5
9.7	110	578	7.5
9.8	108	552	7.5
9.8	110	572	6.5
10.0	108	585	7.0
10.4	108	649	8.0
10.4	110	657	8.0
10.5	107	652	8.0
10.5	108	659	8.0

APPENDIX B

DATA COMPUTED BY METHOD 1
FOR CABLE SCOPES
OF 100, 200, AND 280 FEET

TABLE 8

Data Computed by Method 1 for a
Cable Scope of 100 feet

Speed, knots	Depth, feet	Cable Tension at Ship, pounds	Cable Angle at Ship, degrees
(a) Cable Drag Coefficient C_R = 0.8, f = 0.01			
1.0	99.8	116.9	85.5
3.0	96.0	149.8	65.3
5.0	89.1	221.7	49.9
7.0	83.9	332.4	42.2
9.0	80.7	476.0	38.1
11.0	78.8	658.3	35.9
(b) Cable Drag Coefficient C_R = 0.8, f = 0.02			
1.0	99.8	117.0	85.5
3.0	96.0	150.4	65.3
5.0	89.2	223.4	50.0
7.0	84.0	335.7	42.3
9.0	80.7	481.4	38.2
11.0	78.9	666.3	36.1
(c) Cable Drag Coefficient C_R = 0.8, f = 0.03			
1.0	99.8	117.1	85.5
3.0	96.0	151.0	65.4
5.0	89.2	225.0	50.1
7.0	84.0	338.9	42.4
9.0	80.8	486.7	38.4
11.0	79.0	674.4	36.2

TABLE 8 (continued)

Speed, knots	Depth, feet	Cable Tension at Ship, pounds	Cable Angle at Ship, degrees
(d) Cable Drag Coefficient C_R = 1.5, f = 0.01			
1.0	99.6	117.0	82.7
3.0	90.2	149.4	51.3
5.0	77.6	221.2	34.2
7.0	70.2	333.0	27.4
9.0	66.1	478.2	24.2
11.0	63.8	662.8	22.5
(e) Cable Drag Coefficient C_R = 1.5, f = 0.02			
1.0	99.6	117.1	82.7
3.0	90.2	150.5	51.4
5.0	77.7	224.3	34.4
7.0	70.4	339.1	27.6
9.0	66.2	488.3	24.4
11.0	64.0	677.8	22.7
(f) Cable Drag Coefficient C_R = 1.5, f = 0.03			
1.0	99.6	117.2	82.7
3.0	90.3	151.6	51.5
5.0	77.8	227.5	34.5
7.0	70.5	345.2	27.8
9.0	66.4	498.4	24.6
11.0	64.2	692.9	22.9

TABLE 8 (continued)

Speed, knots	Depth, feet	Cable Tension at Ship, pounds	Cable Angle at Ship, degrees
(g) Cable Drag Coefficient $C_R = 1.8$, f = 0.01			
1.0	99.5	117.0	81.5
3.0	87.5	149.1	46.6
5.0	73.3	221.1	30.0
7.0	65.5	333.4	23.8
9.0	61.3	479.4	20.8
11.0	59.0	665.0	19.3
(h) Cable Drag Coefficient $C_R = 1.8$, f = 0.02			
1.0	99.5	117.1	81.5
3.0	87.5	150.5	46.7
5.0	73.4	224.9	30.1
7.0	65.7	340.7	24.0
9.0	61.5	491.5	21.0
11.0	59.2	683.0	19.6
(i) Cable Drag Coefficient $C_R = 1.8$, f = 0.03			
1.0	99.5	117.3	81.5
3.0	87.6	151.8	46.8
5.0	73.5	228.6	30.3
7.0	65.9	348.0	24.2
9.0	61.7	503.6	21.3
11.0	59.4	701.1	19.8

TABLE 9

Data Computed by Method 1 for a
Cable Scope of 200 feet

Speed, knots	Depth, feet	Cable Tension at Ship, pounds	Cable Angle at Ship, degrees
(a) Cable Drag Coefficient C_R = 0.8, f = 0.01			
1.0	199.4	133.8	83.8
3.0	181.0	164.8	52.7
5.0	155.0	234.5	34.9
7.0	139.3	345.0	27.5
9.0	130.3	489.7	23.9
11.0	125.3	674.2	22.0
(b) Cable Drag Coefficient C_R = 0.8, f = 0.02			
1.0	199.4	134.0	83.3
3.0	181.1	166.0	52.8
5.0	155.2	237.9	35.0
7.0	139.5	351.6	27.7
9.0	130.6	500.5	24.1
11.0	125.7	690.3	22.2
(c) Cable Drag Coefficient C_R = 0.8, f = 0.03			
1.0	199.4	134.1	83.3
3.0	181.2	167.2	52.9
5.0	155.4	241.2	35.2
7.0	139.8	358.1	27.9
9.0	130.9	511.3	24.3
11.0	126.1	706.3	22.4

TABLE 9 (continued)

Speed, knots	Depth, feet	Cable Tension at Ship, pounds	Cable Angle at Ship, degrees
(d) Cable Drag Coefficient C_R = 1.5, f = 0.01			
1.0	198.2	133.8	78.4
3.0	158.1	162.0	36.7
5.0	122.7	231.9	21.8
7.0	106.0	345.1	16.7
9.0	97.2	493.5	14.3
11.0	92.6	682.7	13.0
(e) Cable Drag Coefficient C_R = 1.5, f = 0.02			
1.0	198.2	134.0	78.5
3.0	158.3	164.2	36.8
5.0	123.0	238.2	22.0
7.0	106.4	357.3	16.9
9.0	97.8	513.7	14.5
11.0	93.2	712.8	13.2
(f) Cable Drag Coefficient C_R = 1.5, f = 0.03			
1.0	198.2	134.2	78.5
3.0	158.5	166.5	37.0
5.0	123.4	244.5	22.2
7.0	106.9	369.5	17.1
9.0	98.3	533.9	14.7
11.0	93.7	742.9	13.5

TABLE 9 (continued)

Speed, knots	Depth, feet	Cable Tension at Ship, pounds	Cable Angle at Ship, degrees
(g) Cable Drag Coefficient C_R = 1.8, f = 0.01			
1.0	197.6	133.7	76.4
3.0	149.3	160.9	32.3
5.0	112.8	231.5	18.9
7.0	96.5	345.9	14.4
9.0	88.2	496.0	12.3
11.0	83.8	687.2	11.1
(h) Cable Drag Coefficient C_R = 1.8, f = 0.02			
1.0	197.6	134.0	76.4
3.0	149.6	163.6	32.5
5.0	113.2	239.0	19.1
7.0	97.0	360.6	14.6
9.0	88.7	520.2	12.5
11.0	84.4	723.3	11.4
(i) Cable Drag Coefficient C_R = 1.8, f = 0.03			
1.0	197.6	134.3	76.5
3.0	149.8	166.4	32.7
5.0	113.6	246.5	19.3
7.0	97.5	375.3	14.8
9.0	89.3	544.4	12.7
11.0	84.9	759.4	11.6

TABLE 10

Data Computed by Method 1 for a
Cable Scope of 280 feet

Speed, knots	Depth, feet	Cable Tension at Ship, pounds	Cable Angle at Ship, degrees
(a) Cable Drag Coefficient $C_R^{'}$ = 0.8, f = 0.01			
1.0	278.7	147.3	81.8
3.0	241.7	175.5	46.5
5.0	196.9	242.9	28.9
7.0	172.5	353.2	22.2
9.0	159.1	498.9	18.9
11.0	151.8	685.1	17.2
(b) Cable Drag Coefficient C_R = 0.8, f = 0.02			
1.0	278.7	147.5	81.9
3.0	241.9	177.2	46.6
5.0	197.3	247.3	29.1
7.0	173.0	362.4	22.3
9.0	159.7	514.0	19.1
11.0	152.5	707.6	17.4
(c) Cable Drag Coefficient C_R = 0.8, f = 0.03			
1.0	278.7	147.7	81.9
3.0	242.0	178.9	46.7
5.0	197.7	252.3	29.2
7.0	173.5	371.6	22.5
9.0	160.3	529.1	19.3
11.0	153.1	730.1	17.6

TABLE 10 (continued)

Speed, knots	Depth, feet	Cable Tension at Ship, pounds	Cable Angle at Ship, degrees
(d) Cable Drag Coefficient $C_R = 1.5$, f = 0.01			
1.0	276.2	147.0	75.8
3.0	202.4	170.3	31.1
5.0	149.6	239.0	18.0
7.0	126.6	353.4	13.5
9.0	114.7	504.5	11.3
11.0	108.5	697.4	10.2
(e) Cable Drag Coefficient $C_R = 1.5$, f = 0.02			
1.0	276.2	147.4	75.8
3.0	202.8	173.5	31.3
5.0	150.3	247.8	18.2
7.0	127.3	370.6	13.7
9.0	115.5	532.8	11.6
11.0	109.3	739.5	10.4
(f) Cable Drag Coefficient $C_R = 1.5$, f = 0.03			
1.0	276.2	147.7	75.9
3.0	203.1	176.7	31.4
5.0	150.9	256.6	18.4
7.0	128.1	387.7	13.9
9.0	116.3	561.1	11.8
11.0	110.1	781.7	10.6

TABLE 10 (continued)

Speed, knots	Depth, feet	Cable Tension at Ship, pounds	Cable Angle at Ship, degrees
(g) Cable Drag Coefficient C_R = 1.8, f = 0.01			
1.0	274.8	146.9	73.3
3.0	188.8	168.7	27.3
5.0	136.3	238.5	15.8
7.0	114.4	354.8	11.8
9.0	103.3	508.2	9.8
11.0	97.4	703.9	8.8
(h) Cable Drag Coefficient C_R = 1.8, f = 0.02			
1.0	274.8	147.3	73.4
3.0	189.2	172.5	27.5
5.0	137.0	249.0	15.9
7.0	115.2	375.3	12.0
9.0	104.1	542.1	10.0
11.0	98.3	754.5	9.0
(i) Cable Drag Coefficient C_R = 1.8, f = 0.03			
1.0	274.8	147.7	73.4
3.0	189.6	176.3	27.2
5.0	137.7	259.5	16.1
7.0	116.0	395.9	12.2
9.0	105.0	576.0	10.2
11.0	99.2	805.0	9.2

APPENDIX C

DATA COMPUTED BY METHOD 2
FOR CABLE SCOPES
OF 100, 200, AND 280 FEET

TABLE 11

Data Computed by Method 2 for a
Cable Scope of 100 feet

Speed, knots	Depth, feet	Cable Tension at Ship, pounds	Cable Angle at Ship, degrees
(a) Cable Drag Coefficient C_R = 0.8			
1.0	99.8	116.9	85.5
3.0	96.0	150.4	65.3
5.0	89.2	224.7	50.0
7.0	84.0	339.6	42.4
9.0	80.8	488.9	38.3
11.0	78.9	678.3	36.2
(b) Cable Drag Coefficient C_R = 1.5			
1.0	99.6	116.9	82.7
3.0	90.2	151.2	51.4
5.0	77.8	229.0	34.5
7.0	70.5	350.0	27.9
9.0	66.4	507.8	24.7
11.0	64.2	708.0	23.0
(c) Cable Drag Coefficient C_R = 1.8			
1.0	99.5	116.9	81.5
3.0	87.5	151.6	46.7
5.0	73.5	231.1	30.3
7.0	65.9	354.9	24.3
9.0	61.7	516.4	21.4
11.0	59.5	721.3	19.9

TABLE 12

Data Computed by Method 2 for a Cable Scope of 200 feet

Speed, knots	Depth, feet	Cable Tension at Ship, pounds	Cable Angle at Ship, degrees
(a) Cable Drag Coefficient $C_R = 0.8$			
1.0	199.4	133.8	83.3
3.0	181.1	166.7	52.8
5.0	155.4	242.9	35.2
7.0	139.8	363.5	27.9
9.0	131.0	521.7	24.4
11.0	126.1	723.0	22.6
(b) Cable Drag Coefficient $C_R = 1.5$			
1.0	198.2	133.7	78.4
3.0	158.4	167.4	36.9
5.0	123.5	251.0	22.3
7.0	107.1	384.7	17.3
9.0	98.6	560.7	14.9
11.0	94.0	784.0	13.7
(c) Cable Drag Coefficient $C_R = 1.8$			
1.0	197.6	133.7	76.4
3.0	149.7	168.0	32.7
5.0	113.7	255.2	19.5
7.0	97.8	394.7	15.0
9.0	89.7	578.3	12.9
11.0	85.4	811.2	11.8

TABLE 13

Data Computed by Method 2 for a
Cable Scope of 280 feet

Speed, knots	Depth, feet	Cable Tension at Ship, pounds	Cable Angle at Ship, degrees
(a) Cable Drag Coefficient C_R = 0.8			
1.0	278.7	147.2	81.8
3.0	241.9	178.9	46.6
5.0	197.7	256.0	29.3
7.0	173.6	381.2	22.7
9.0	160.5	546.8	19.4
11.0	153.4	757.8	17.8
(b) Cable Drag Coefficient C_R = 1.5			
1.0	276.2	147.1	75.8
3.0	203.0	178.9	31.4
5.0	151.1	267.3	18.6
7.0	128.5	411.4	14.1
9.0	116.9	602.0	12.0
11.0	110.8	844.1	10.9
(c) Cable Drag Coefficient C_R = 1.8			
1.0	274.8	147.0	73.3
3.0	189.6	179.6	27.7
5.0	138.0	273.4	16.3
7.0	116.5	425.7	12.4
9.0	105.7	627.1	10.5
11.0	99.9	882.5	9.5

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Two alternative methods for predicting steady-state configurations
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experimental data. Between the two methods, Method 1 is shown to
provide better overall predictions of cable tension, cable angle at towing
ship, and body depth for the bare-cable case. The best agreement
between the experimental data and the data predicted by Method 1 is
obtained with a cable drag coefficient of 1.5 and a tangential force factor
of 0.02.

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14. KEY WORDS	LINK A		LINK B		LINK C	
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14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, roles, and weights is optional.

David Taylor Model Basin. Report 2313.
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SYSTEM USING BARE CABLE, by Thomas Gibbons and
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